Institute of Paper Science and Technology
Atlanta, Georgia

IPST Technical Paper Series Number 797

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June 1999

Submitted to
1999 TAPPI Engineering/Process & Product Quality Conference
September 12-16
Anaheim, California

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CHARACTERIZING PULPS FOR PAPER-MACHINE RUNNABILITY

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ABSTRACT
Paper-machine productivity is dependent on a balance between water removal and the end-use performance of the paper being produced. This brief overview focuses on the water removal aspects of the papermaking process from the furnish to the dryer section.

INTRODUCTION
Simplistically papermaking is a process of network formation, consolidation, and water removal. Furthermore, water removal has to be balanced with achieving a desired end-use performance for the product being produced. All stages of the papermaking process can affect water removal and ultimately the productivity of the paper-machine, as shown in Figure 1. Generally, the higher the basis weight of the paper or board being produced, the lower the paper-machine speed or productivity, as illustrated in Figure 2. The speeds shown in Figure 2 are close to the highest recorded for that particular product. Paper-machine productivity is not always limited by water removal considerations but may be dependent on strength or mechanical factors. For example, the runnability of many paper products both on and off the paper-machine is dependent on the use of reinforcing pulps, a more costly furnish component, which many mills would like to reduce.

Canadian Standard Freeness (CSF) and similar drainage testers are often central to controversial arguments surrounding the water removal of a pulp and their usefulness in characterizing paper-machine productivity. The demise of the CSF or Schopper Riegler (SR) is perhaps best illustrated by the program booklet to a 1972 symposium on pulp characterization held at Ronneby in Sweden (1), which showed on the front cover an SR deposited in the scrap box. For many reasons, this tester has refused to die. Nevertheless, paper-machine speed has been directly related to °SR (2), as shown in Figure 3. Under certain circumstances, this may be true. However, it is clear that other papermaking factors, particularly at the wet-end of the paper-machine, e.g., wet end chemistry, former type, and drainage elements can easily invalidate such a relationship. We will return to this subject in due course.

In this paper we will briefly examine the various factors controlling water removal in the papermaking process and the means for characterizing the water removal behavior of a pulp. This will set the scene and provide a backdrop for the papers to follow.

It may be said at the outset that pulp characterization methods for various parts of the papermaking process have greatly improved in recent years. Nevertheless, there is still the need for a unified approach, which will be adequate to predict water removal on the paper-machine.

FURNISH
Fiber type(s), pulping and bleaching sequences will, in general, control the drainage and water removal potential of a pulp. Recycled fiber, filler, synthetic fibers, etc., are other furnish components that may impact water removal. In general, as pulp yield is reduced, the amount of water associated with the fiber increases. This is illustrated in Figure 4 using the data of Scallan (3), who shows, for the kraft and sulfite pulping processes, the fiber saturation point (fsp), i.e., the water within the cell wall of the fiber, increases with decreasing yield and goes through a maximum around a yield of 60%.

STOCK PREPARATION
Stock preparation includes screening, cleaning, deaeration, refining, and consistency control. Each of these may impact the furnishes water removal performance, however; refining is usually the most important.

Refining is capable of producing many changes in fiber structure, which can affect the water removal behavior of a furnish, as shown in Table 1. Also shown in Table 1 are some of the methods used to quantitatively determine these changes.

In fact, we use changes in water removal behavior to monitor the extent to which a furnish has been refined. These methods include drainage tests, e.g., CSF, SR, William Slowness, water retention value (WRV), constant head filtration and mat compressibility measurements.

Table 1 Changes in Fiber Structure Produced by Refining

REFINING EFFECT	MEASUREMENT TECHNIQUES
Internal Changes in Fiber Structure	Specific Volume, WRV, fsp,
External Changes in Fiber Structure	Hydrodynamic Specific Surface Area
Fines Production	Britt Jar ≥ 200 mesh
Changes in Fiber Length	Image analysis, Kajaani, Bauer McNett
Changes in Fiber Cross Section	TEM, Confocal Microscopy,
Changes in Fiber Kinks, Curl	Image Analysis, FQA
Changes in Cell Wall Microcompressions	Microscopy
Dissolution of Cell Wall Materials	Chemical Analysis
Gelatinization of the Cell Wall	

Unfortunately, the trade-off (or sacrifice) has been between a simple rapid test to determine the effects of refining and a more detailed knowledge of those changes as exemplified by some of the methods given in Table 1.

CSF is one such example. On occasion, it can provide a fairly accurate statement with regard to changes that have occurred as a result of refining, as well as relate to paper-machine productivity, as illustrated in Figure 3. The CSF, which involves a more complex drainage situation than , say, constant head filtration through a well-formed mat, has been criticized (4), (7), (8), (22) as well as defended (5), (6), (9).

Hosseiny and Yan, in Part I of their paper, (5) demonstrated using Darcy's law that the logarithm of CSF is related to the square root of the average filtration resistance. In Part II, they showed that CSF is mainly controlled by the pulp's hydrodynamic specific surface area, and; to a much lesser extent, the hydrodynamic specific volume. In a later study, Swodinski and Doshi (6) extended the analysis for the SR test and its relationship to CSF.

CSF should be sensitive to the level and type of fines production. This is illustrated in Figure 5, which shows the variation of CSF with fines content for a never-dried and recycled pulp (9). At the other extreme, Hartman (10) has shown, using a roll refining process, that if refining can be carried out without fines production, then there will be no change in CSF. Nevertheless, roll refining did produce internal changes in fiber structure and concomitant improvements in strength.

It is also interesting to note that on-line drainage testers developed to monitor and control refining are strongly correlated with CSF (11).

PAPER-MACHINE WET END

One of the often disappointing outcomes of simple pulp characterization methods such as CSF is its inability to predict the pulps wet-end paper-machine performance. The pulp's drainage performance on the paper-machine is clearly complicated by a number of factors, including the type of former and drainage elements and the often conflicting triad of retention, drainage, and formation. Various approaches developed to resolve this situation are outlined below.

Wet-End Chemistry - Retention, drainage, formation.

Lindstrom (12) has presented a very complete picture of the many facets of wet end chemistry focusing primarily on retention chemistry. It is clear that when fillers and retention aids are used, the furnish and, hence, its water removal behavior becomes a lot more complex. For example, microparticulate retention/dewatering aids systems are characterized by the addition of a cationic polymer followed by the addition of an anionic submicron particle suspension. According to Lindstrom, (12) these exhibit a strong dewatering action in both the wire and press sections of the paper-machine. On the other hand, formation aids appear to have an adverse effect on drainage rate and, therefore, find limited usage.

Former type and drainage elements.

The following discussion briefly highlights some of the developments associated with water removal in the forming section of the paper-machine and is not intended to be a thorough analysis of the literature in this domain.

Britt, Unbehend, and Holman (13) again point out the limitations of freeness testers to predict drainage on the paper-machine. They considered that the following parameters would need to be controlled within the ranges applicable to the fourdrinier paper-machine, i.e., consistency, volume, basis weight, vacuum, turbulence, and formation time. The equipment they used to simulate more realistic paper-machine drainage conditions was a modified form of the Britt dynamic drainage jar. Water removal, as measured by the final consistency of the web, was influenced by fines content, particularly above 15%. A dual-component retention aid was particularly effective in increasing water removal in this fines content range.

In a later contribution, Brita and Unbend (14) address the issue of water removal in the forming zone and the vacuum zone of the paper-machine and the conflicting pulp requirements, i.e., a low-fines-content, free-draining stock performs better in the forming zone. Whereas, a more closed sheet, i.e., higher fines content, performs better in the vacuum zone with respect to water removal.

More sophisticated attempts to realistically simulate dynamic drainage conditions include the Moving Belt Drainage Tester (MBDT) developed by Karrila, Paulaporo, and Raisanen (15). It has been used by these authors to investigate the optimization of high vacuum dewatering (16), (17).

Sutman (18), in response to the limitations of freeness testing, has more recently developed an improved version of the BetzDearborn Pulsed Drainage Device (BPDD). The design was changed to improve web consolidation by thickening and minimize filtration effects. The main response variables of the test are corrected drainage time, peak to equilibrium vacuum ratio, and first-pass fines retention. Careful replication and statistical analysis are required to achieve dependable results. The new tester supposedly can provide a more complete picture of the combined effects of retention, drainage, and formation.

This brief look at the simulation of paper-machine drainage has not yet revealed the need for any new pulp parameters. However, a theoretical analysis of the complex drainage and vacuum zones and comparison with experiments might reveal such needs, e.g., the viscoelastic behavior of the suspension. This subject was discussed by Kyrklund in a paper titled "Volume Rheology of Pulp" at the Ronneby meeting (1).

WET PRESSING

Mechanical consolidation and water removal from the web during wet pressing will be dependent on a number of factors, including press configuration, clothing, and the ingoing moisture content of the web to the press section, i.e., couch consistency and web uniformity. After couching, both inter and intrafiber water is present.

Stratton (19) has shown that hydrodynamic specific volume is a good indicator of water removal in the press section. Figure 6 shows the increase in press solids with swollen volume for a softwood bleached kraft pulp at different levels of refining. The ingoing solids level to the press was 30%. When specific surface area was used, a separate curve was obtained for each level of refining. This result is perhaps not too surprising since at 30% solids level the water to be removed is mainly intrafiber water.

Scallan (20) has also shown that the fiber saturation point (fsp) is an important variable characterizing water removal in the press section, as illustrated in Figure 7 for a variety of fines free pulps. Scallan's novel approach allowed him to determine the relative amounts of inter- and intrafiber water removed as a function of wet-pressing pressure. Figure 7 was obtained for a pressure of 54 MPa, where the water remaining is essentially all intrafiber water. One key assumption is that water expelled from the fiber is also drained from the mat.

Scallan and Carles (21) have also demonstrated that (fsp) correlates with the water retention value (WRV), although fines-containing and highly swollen pulps can be problematical. Therefore, there is some degree of confidence that (WRV) could also be an effective measure of water removal in the press section.

Despite the complexities of wet pressing, e.g., rewetting and moisture gradients within the web, no additional parameters have yet appeared for characterizing the wet-pressing potential of a pulp. Nordman (22), in addition to suggesting that drainage tests be established under realistic conditions, thought that wet web compressibility, fiber collapse, and fiber damage might be worthy candidates.

DRYING

It is generally agreed that the less water one has to remove in the dryer section the lower the cost of water removal. As with the press section, it might be anticipated that improved sheet formation would make cylinder drying more efficient. Other considerations might include the porosity or openness of the sheet, particularly when one is dealing with through drying. Interestingly, we do not have a fiber or web characterization parameter that directly relates to water removal in the dryer section.

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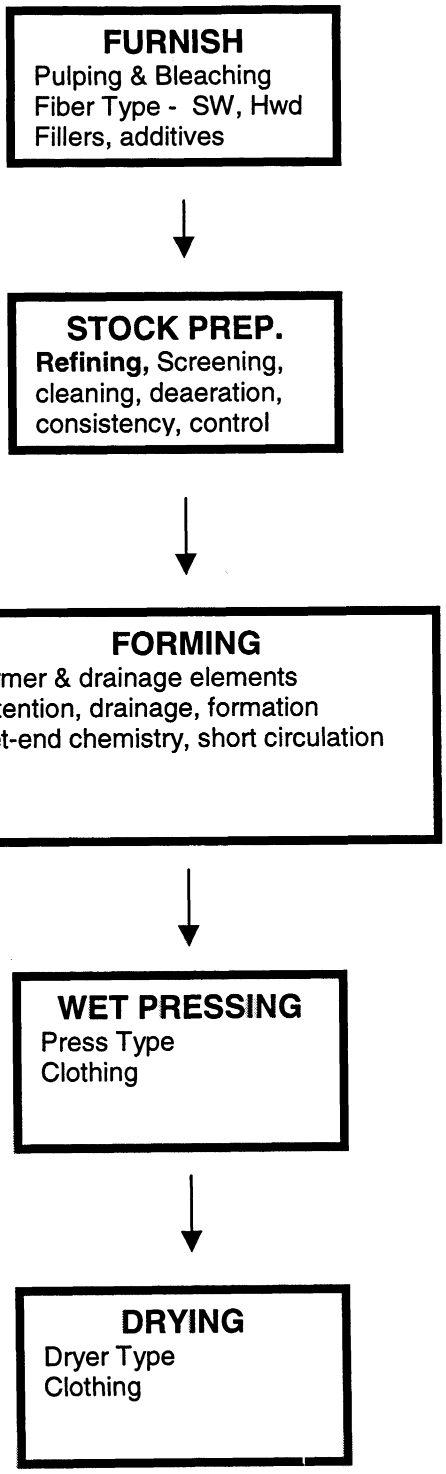

Figure 1 **Stages and Factors Controlling Water Removal in the Papermaking Process**

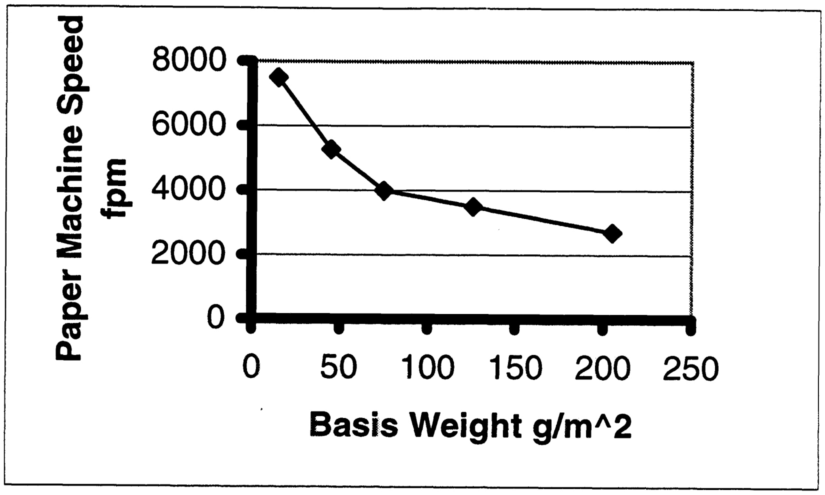

Figure 2 **Paper-Machine Speed Versus Basis Weight**

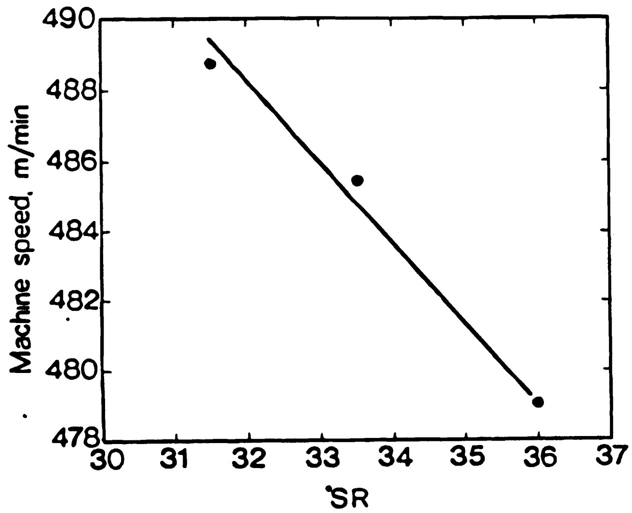

Figure 3 **Paper-Machine Speed Versus °SR (taken from de Ruvo and Htun (2))**

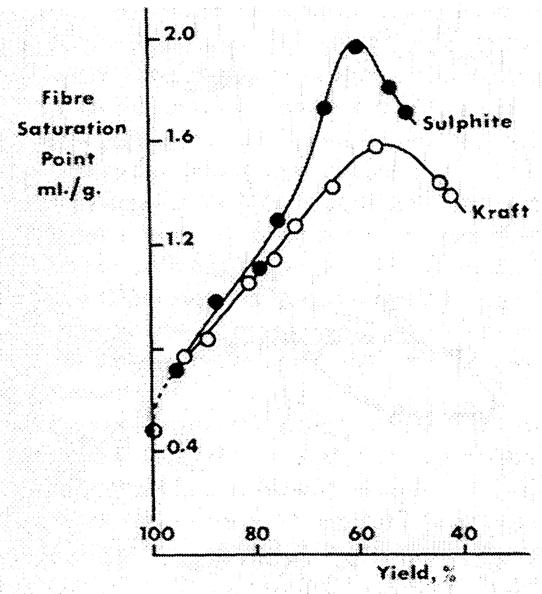

Fig. 2—The variation of the fibre saturation point with pulping yield for a number of pulps prepared from sprucewood[10]

Figure 4 **Variation of Fiber Saturation Point with Pulp Yield (taken from A.M. Scallan (3))**

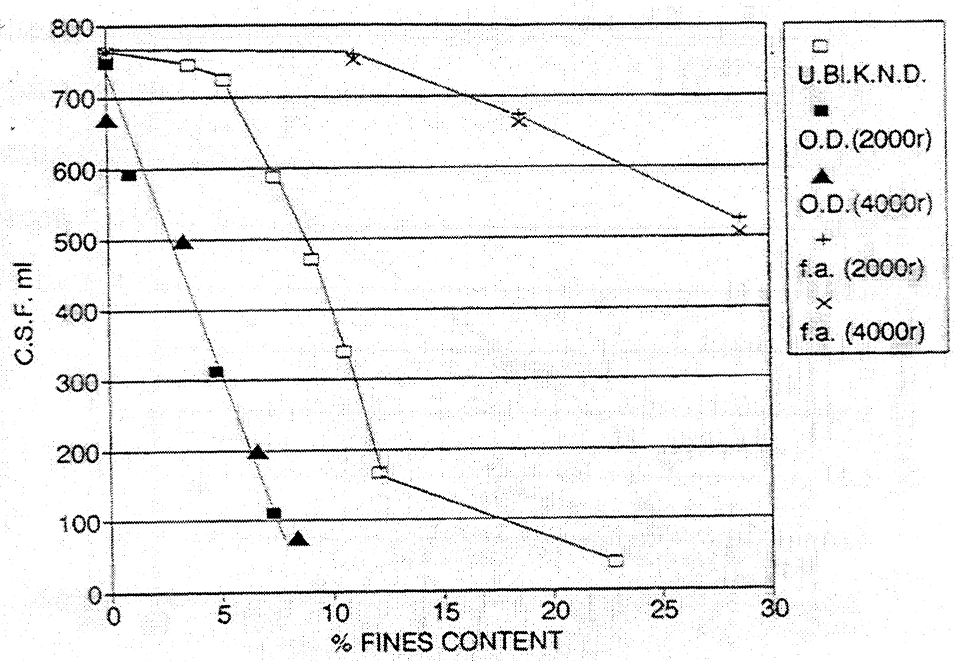

Figure 5 **Variation of CSF with Fines Content for Never-Dried and Once-Dried Fines**

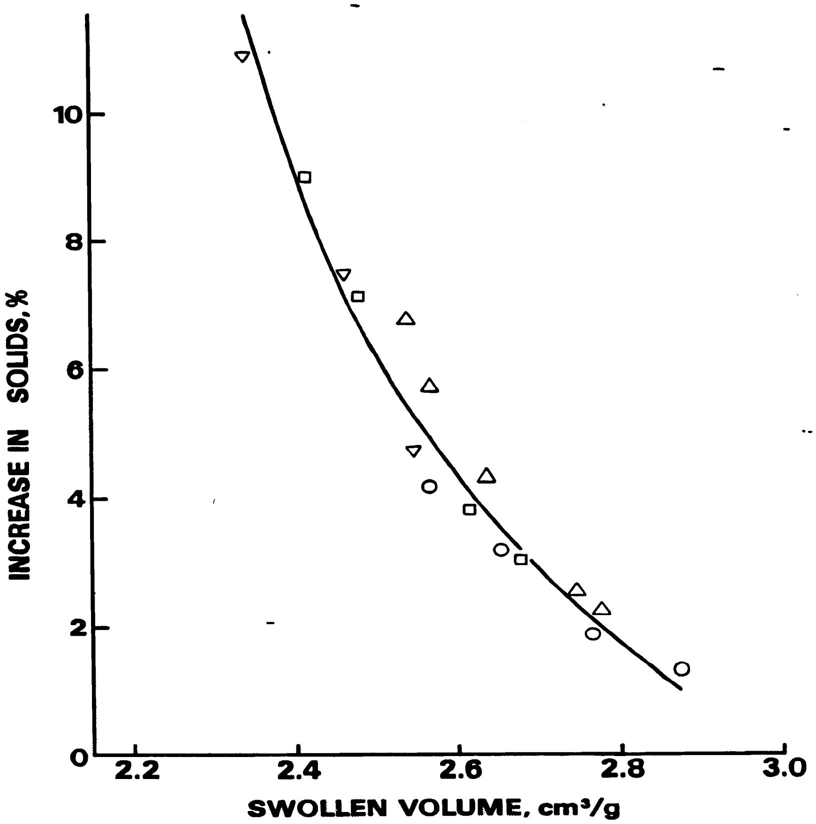

Figure 6 Variation of Increase in Solids Due to Wet Pressing with Hydrodynamic Specific Volume (taken from Stratton (19)).

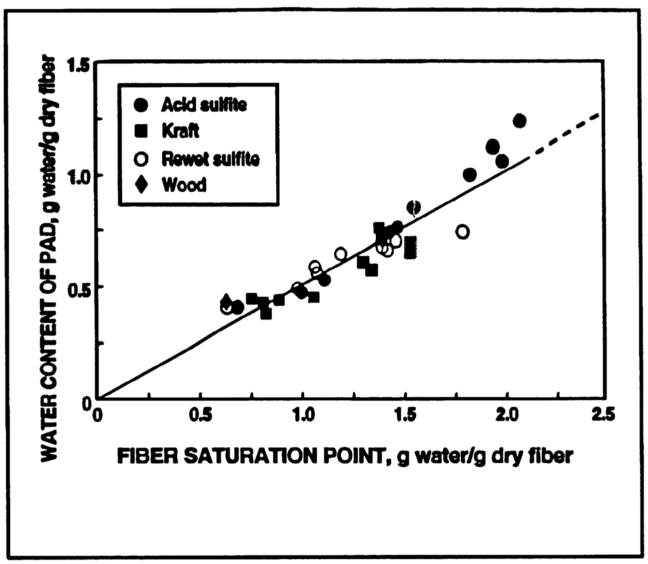

Figure 7 Variation of Water Content of Pad Due to Wet Pressing with Fiber Saturation Point at a Constant Pressure of 54 MPa (taken from Scallan (21))